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Recent Results from Infrared Observations of White Dwarfs, their Companions, and the Dust that Surrounds Them

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Abstract. Although "traditionally" observed at short wavelengths, white dwarfs have displayed many surprising features when probed in the infrared. We present an overview of recent results from ground- and space-based near- to mid-infrared observations of white dwarfs. These include the discovery of many new candidate binary stars containing low mass stellar or sub-stellar companions from a sample of objects previously thought to be single white dwarfs, and Spitzer Space Telescope observations that suggest that dust is common in the environs of white dwarfs in cataclysmic variables.

1. Unusual Variable in Hercules (Var Her 04)

On 2004 June 16, a previously unknown star in Hercules went into outburst (Nakano et al. 2004). Based on the large outburst amplitude ($\Delta V > 4.5$ mag), presence of superhumps in the light curve, and very short orbital period ($P_{\rm orb} =$ 81.8 min), Var Her 04 was identified as a Tremendous Outburst Amplitude Dwarf Nova (TOAD; e.g., Howell et al. 1995). For a given TOAD, superoutbursts are rare (recurrence times of decades), so we took advantage of this opportunity to observe the outburst with the Spitzer Space Telescope. During the subsequent year, we obtained two observations with IRAC (3.0, 4.5, 5.6, 8.0 μm) and four observations with MIPS (24 μm) to investigate the formation of dust in the ejecta of TOAD superoutbursts.

Our Spitzer photometry of Var Her 04 is contaminated by a nearby ($1''$) foreground star that is unrelated to the variable. We have identified this neighbor as a normal M3.5 V star based on its near-IR colors (e.g., resolved photometry from Price et al. 2004) and comparison with near- to mid-IR spectral templates. Regardless, our Spitzer observations show variability over the stable level of the foreground star that is attributed to Var Her 04 (see Figure 1).

Based on the increase in 24 μm flux density during our MIPS-2 measurement, we estimate that 10^{-13}–$10^{-11} M_\odot$ of dust was produced by Var Her 04, for dust temperatures of 400–100 K, respectively (see Figure 2). Theory predicts there are 10^4–10^5 TOADs in the Galaxy (e.g., Howell et al. 2001). If each TOAD outbursts, on average, once every 10 years, then there may be 10^3–10^4 outbursts per year throughout the Galaxy. If each outburst produces the same amount of dust as Var Her 04, then this corresponds to 10^{-10}–$10^{-8} M_\odot$ injected into the ISM per year. On average there is one classical nova per year in the Galaxy, which ejects 10^{-9}–$10^{-6} M_\odot$ of dust into the ISM (Gehrz et al. 1998), perhaps

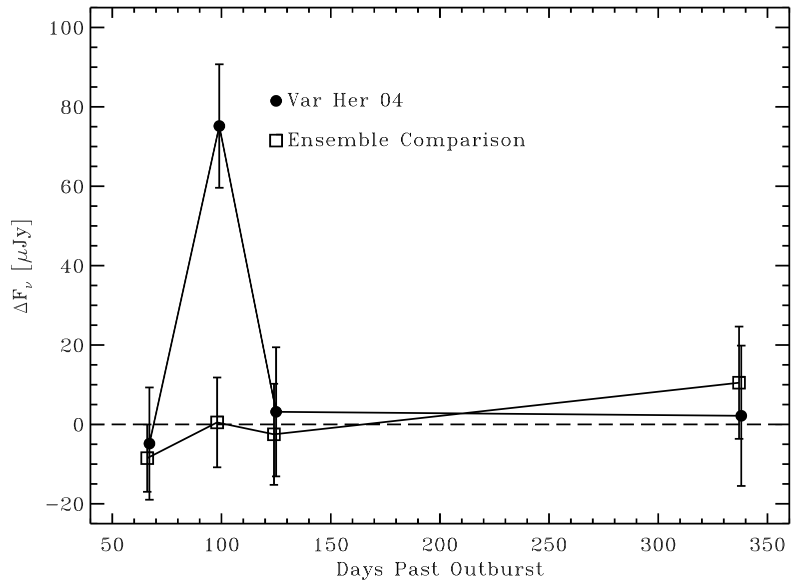

Figure 1. Time-resolved 24 μm photometry of Var Her 04 and the unresolved foreground star (filled circles), in comparison to an ensemble of four field stars (unfilled squares). The mean of the ensemble has been defined as the zero level (dashed line). The second MIPS point marks the detection of excess 24 μm flux density from Var Her 04 due to the formation of dust in the outburst ejecta.

making the total population of TOADs as important as classical novae in the recycling and enriching of the ISM (Ciardi et al. 2006).

2. White Dwarf + Red Dwarf Binaries

We are exploring the frequency of binary stars containing a white dwarf (WD) and low mass (sub-)stellar companion. We have already identified ~ 50 new binary candidates from the WD sample of McCook & Sion (1999) using data from the 2MASS Second Incremental Data Release (Wachter et al. 2003); we are now completing this survey using the 2MASS All Sky Data Release. As we found in Wachter et al. (2003), there is a locus of WDs in the 2MASS color–color diagram that have colors consistent with low mass main sequence stars – these are candidate binaries (see Figure 3). The vertical "bridge" at $(H - K_{\rm s}) \approx 0.3$ that joins this locus with the bulk of the WDs in Figure 3 likely contains binaries with very low mass, probably substellar, companions. We predicted the existence of such a feature in Wachter et al. (2003) using simulated binaries (see their Figure 2). Many of the candidates from Wachter et al. (2003) have already been verified as close binaries from our HST/ACS snapshot imaging survey (see Figure 4). A large sample of newly identified binaries will allow us to empirically test binary star parameters in the post-AGB phase and begin to address the fundamental astrophysical question of how stellar evolution influences the observed distribution of binary star parameters (e.g., orbital separation).

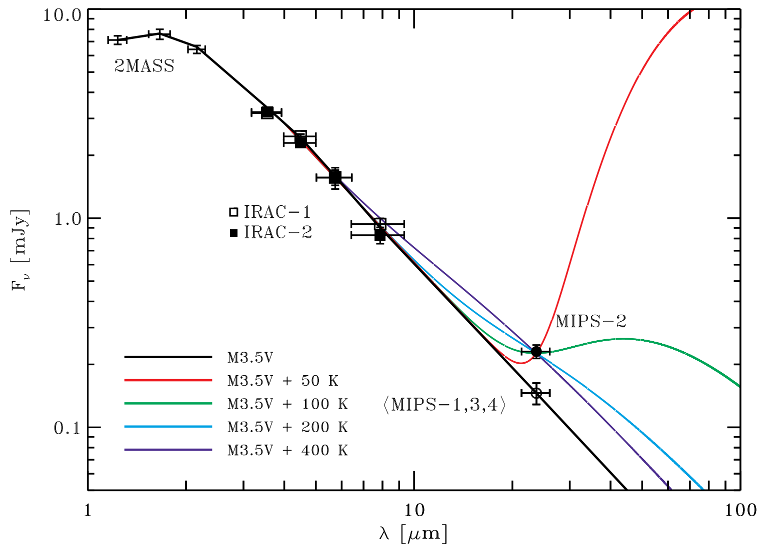

Figure 2. Spectral energy distribution for the unresolved photometry of Var Her 04 and the foreground M dwarf (points), with an M3.5 V template (Patten et al. 2006) scaled to the 2MASS *J*-band point (black line). We also show four different blackbody curves that are forced to pass through the bright MIPS-2 data point, to represent the dust emission (ordered from top to bottom on the right side of the plot as listed in the plot legend).

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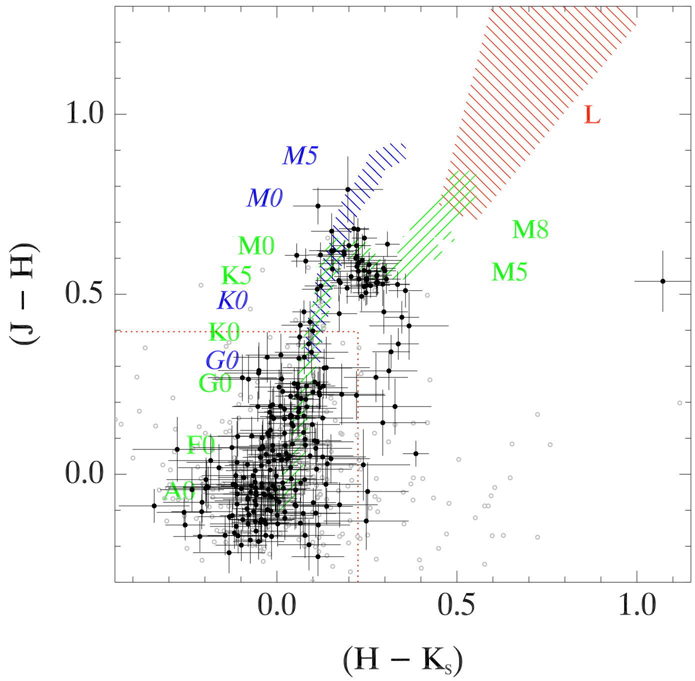

Figure 3. In-progress infrared color–color diagram showing nearly all of the WDs from the McCook & Sion sample that were not contained in the 2MASS Second Incremental Data Release (filled circles; unfilled circles have one or more JHK_s photometric uncertainty > 0.1 mag). The regions occupied by the main sequence (green /// hatched area), giant branch (blue \\\ hatched area), and L dwarfs (red \\\ hatched area) are also shown.

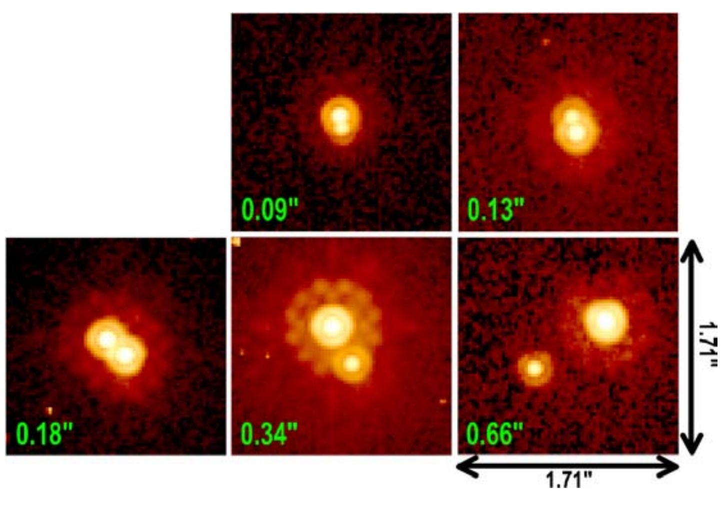

Figure 4. Representative Hubble Space Telescope ACS/HRC (F814W) images of resolved WD + low mass star binaries selected from the sample of allegedly single WDs via infrared excess in the 2MASS color–color diagram (Farihi et al. 2006; Wachter et al. 2003). Note the range of separations of the binary components (lower left corner of each image panel).